Fiber Optic Temperature Sensor for PEM Fuel Cells

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UT-BATTELLE

Program Goals: Temperature Sensing

Program Target

- Operating Range: -40 to 150 C
- Response time: <0.5 sec with 1.5% accuracy (-40 to 100 C)
  <1 sec with 2 % accuracy (100 to 150 C)
- Gas environment
- Insensitive to flow velocity

Demonstrated by ORNL

- Operating Range: -250 to 1700 C
- Response time: <0.001 sec with 1.0% accuracy (-0 to 750 C)
- Gas environment: inside operating jet engine, induction furnace, and many laboratory atmospheres including PEM/MEA
- Insensitive to flow velocity: needs to be tested

Project Objectives

- Develop a low cost, robust temperature sensor for monitoring fuel cell condition and performance;
- Develop a fiber optic probe that could provide intra-cell thermal information;
  - thermal mapping;
  - location of hot spots;
- Develop a low-cost architecture for integrating the FO temperature sensor into the fuel cell control electronics -> plug-and-play modular design; and
- Establish a partnership with an approved equipment vendor to facilitate technology commercialization and implementation.

Why a Waveguide Temperature Sensor?

- Reliability - fiber optic sensors are immune to oxidizing or reducing atmospheres, they are electrical insulators and don't drift over time
- Speed - temperature measurements can be made in milli- to micro-seconds
- Simplicity - a fluorescent material, optical waveguide, LED, detector and some simple signal processing are all that is required
- Cost - the production cost is potentially very low, <$5.00
- Flexibility - our concepts will provide single point or multiple measurements of temperature and may enable measurement of other parameters (e.g. thermal gradients, stack compression uniformity and humidity)

FreedomCAR

Approach: Fluorescence Temperature Sensing

- Atoms in a matrix have electrons thermally excited
- Excited electrons de-excite
  - Radiative and Non-radiative processes compete
  - Non-radiative process increases with temperature
- Time characteristic of the net radiative de-excitation indicates temperature

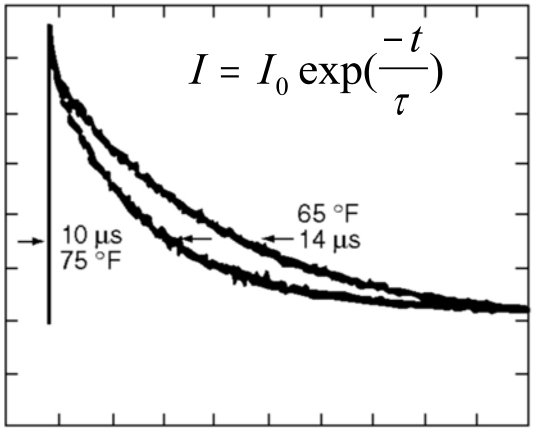
We will exploit this radiative (fluorescence) behavior to measure temperature.

Approach: Fluorescence Temperature Sensing

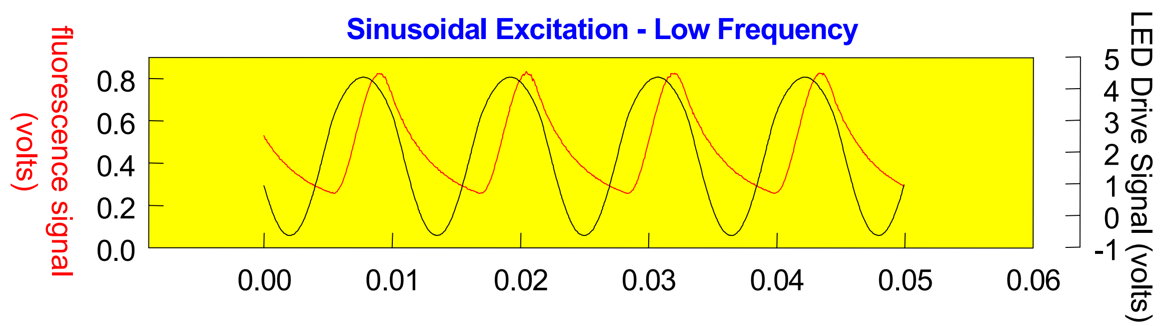
Temperature sensitive phosphor illuminated by excitation light from LED or laser diode

Phosphor glows. If excited by a short pulse, the glow duration indicates temperature. If excited by an oscillating signal, temperature is indicated by phase shift.

$$\tan(\phi) = 2\pi f \tau \quad \text{where } \tau = f(T)$$



Time Dependence of a Fluorescence Signal at Two Temperatures



Approach: Fluorescence Temperature Sensing

Choosing the best phosphor for the measurement of interest is critical.

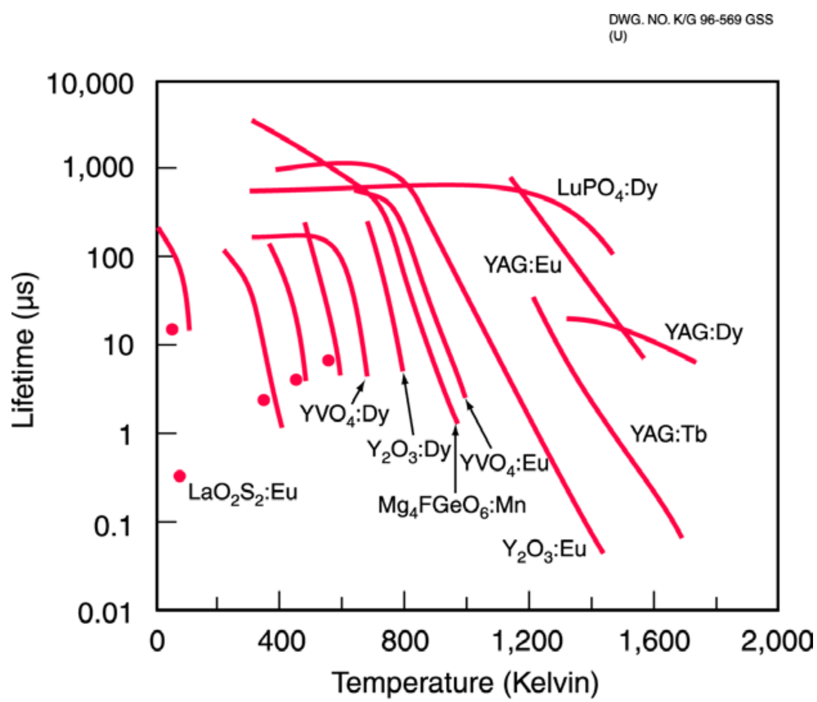
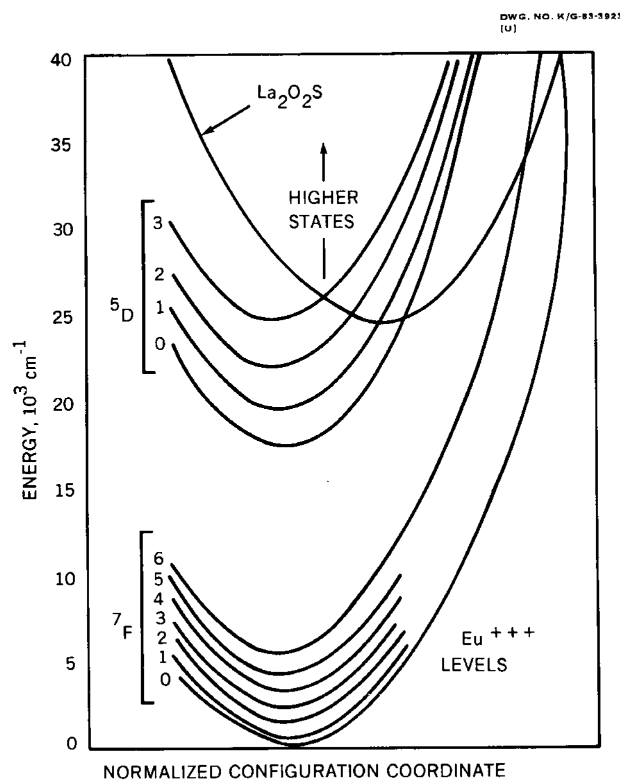
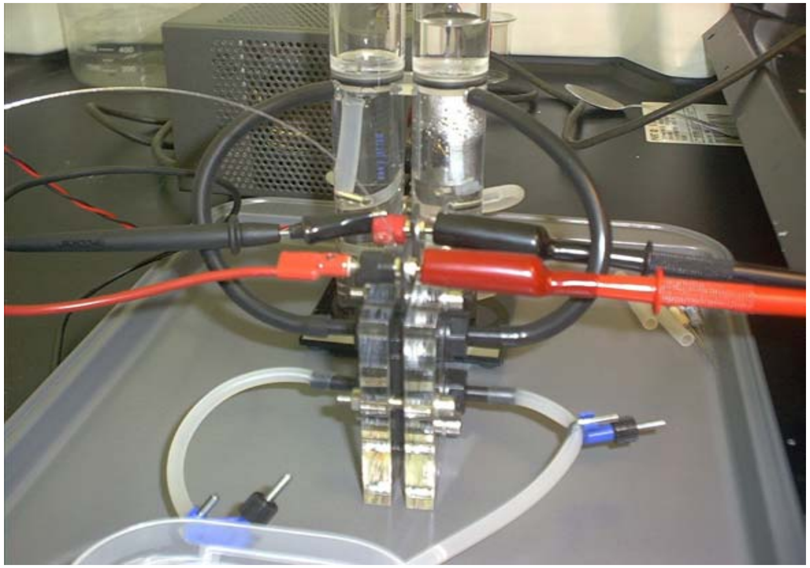


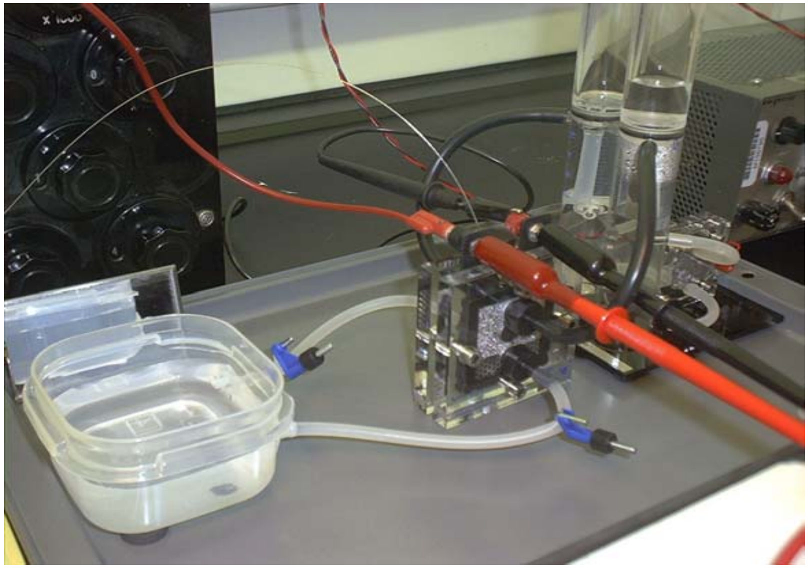
Figure 12. Lifetime versus temperature of selected phosphors.



Approach: Our Current Laboratory Setup

Fuel cell demo kit with 400 micron fiber inserted.

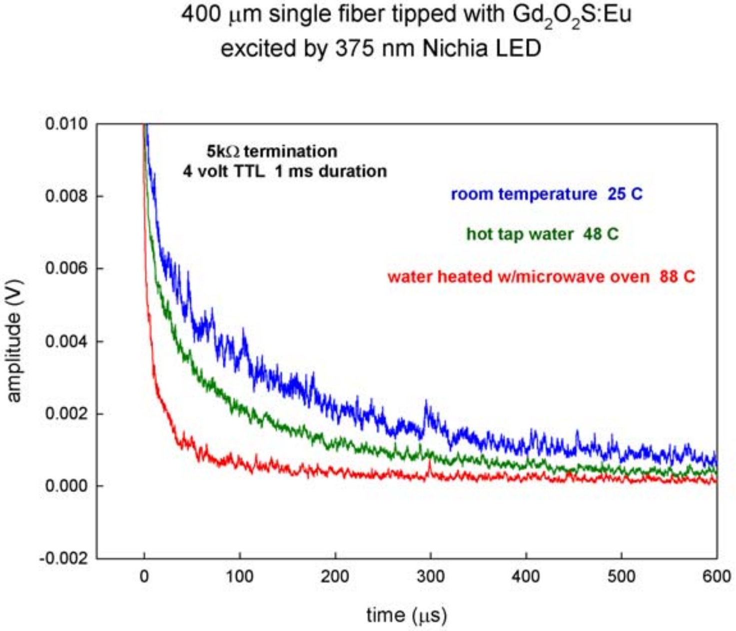


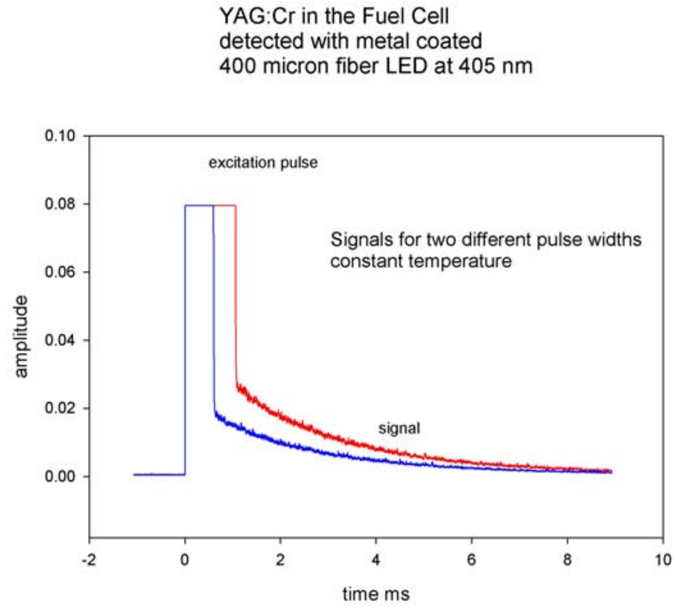


Demonstrated a temperature measurement without causing degradation to fuel cell performance.

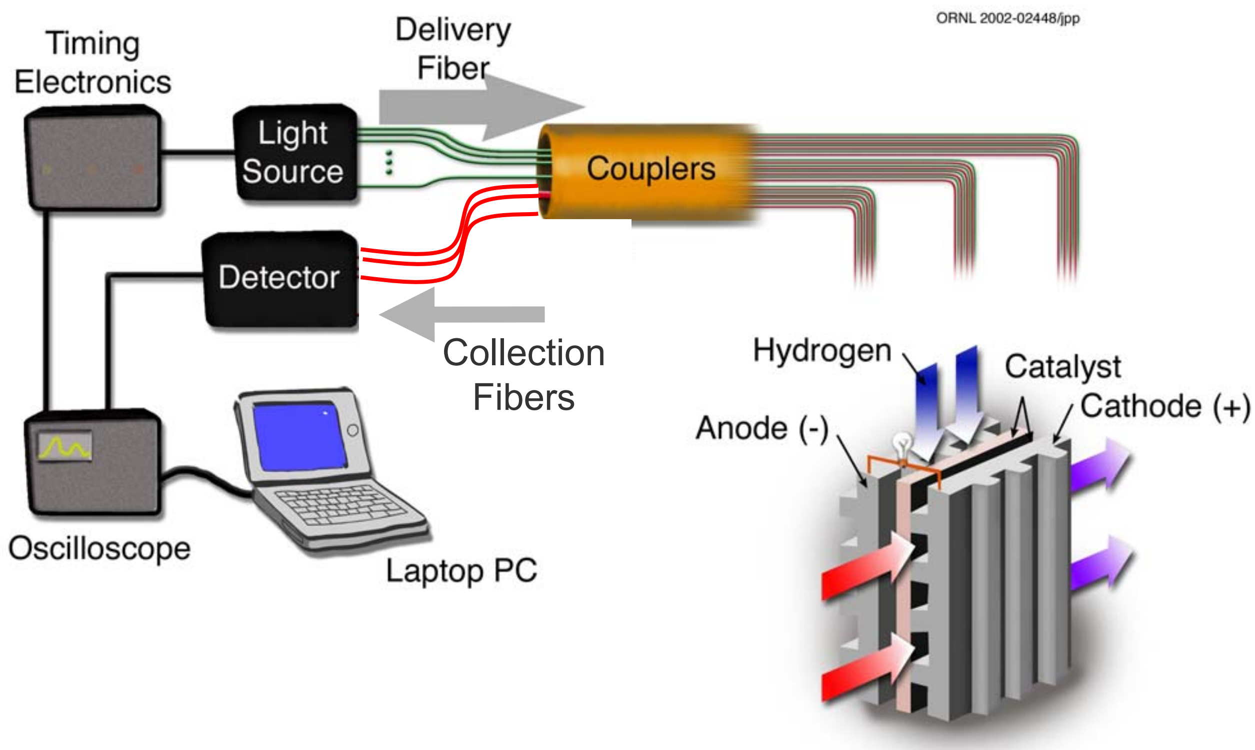
Approach: Some Preliminary Probe Data

Signals from Phosphor-tipped Fibers



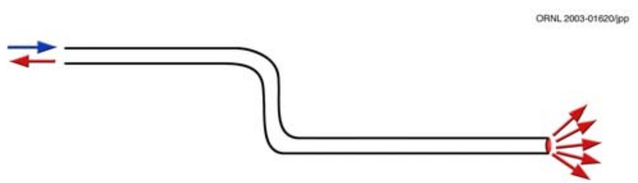


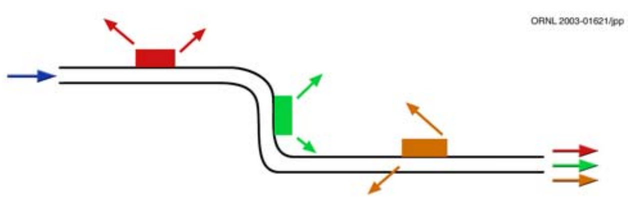
Approach: Our Future Setup to Explore Probe Designs

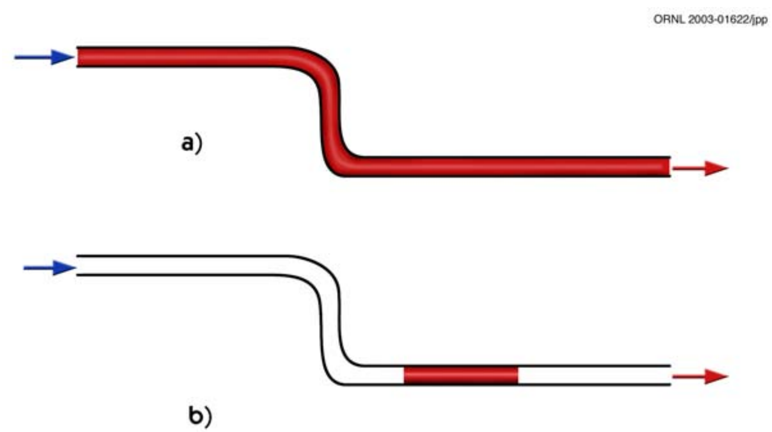


Approach: Various Probe Options Will Be Explored

Ways to exploit the concept of fluorescence in conjunction with optical fibers for measuring temperature





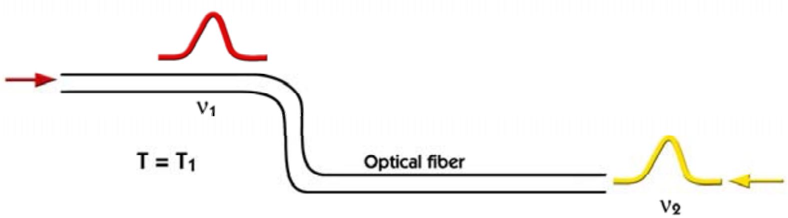


Phosphors coated onto fiber end and side provide highly localized temperature sensing

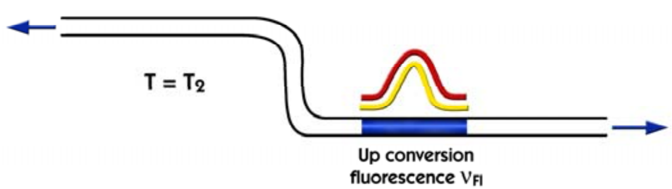
Rare earth doped fiber provides increased signal and offers novel sensing method

Some Advanced Concepts are Emerging

Two Photon Excitation

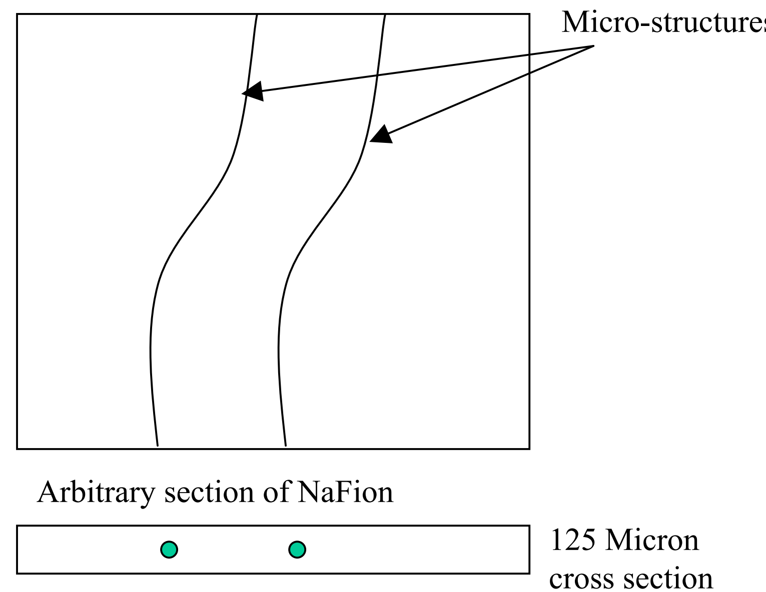


Spatially Resolved Sensing



Embedded Micro-structures in PEM

(Initial test sample)



Accomplishments

Project Began in January, 2003

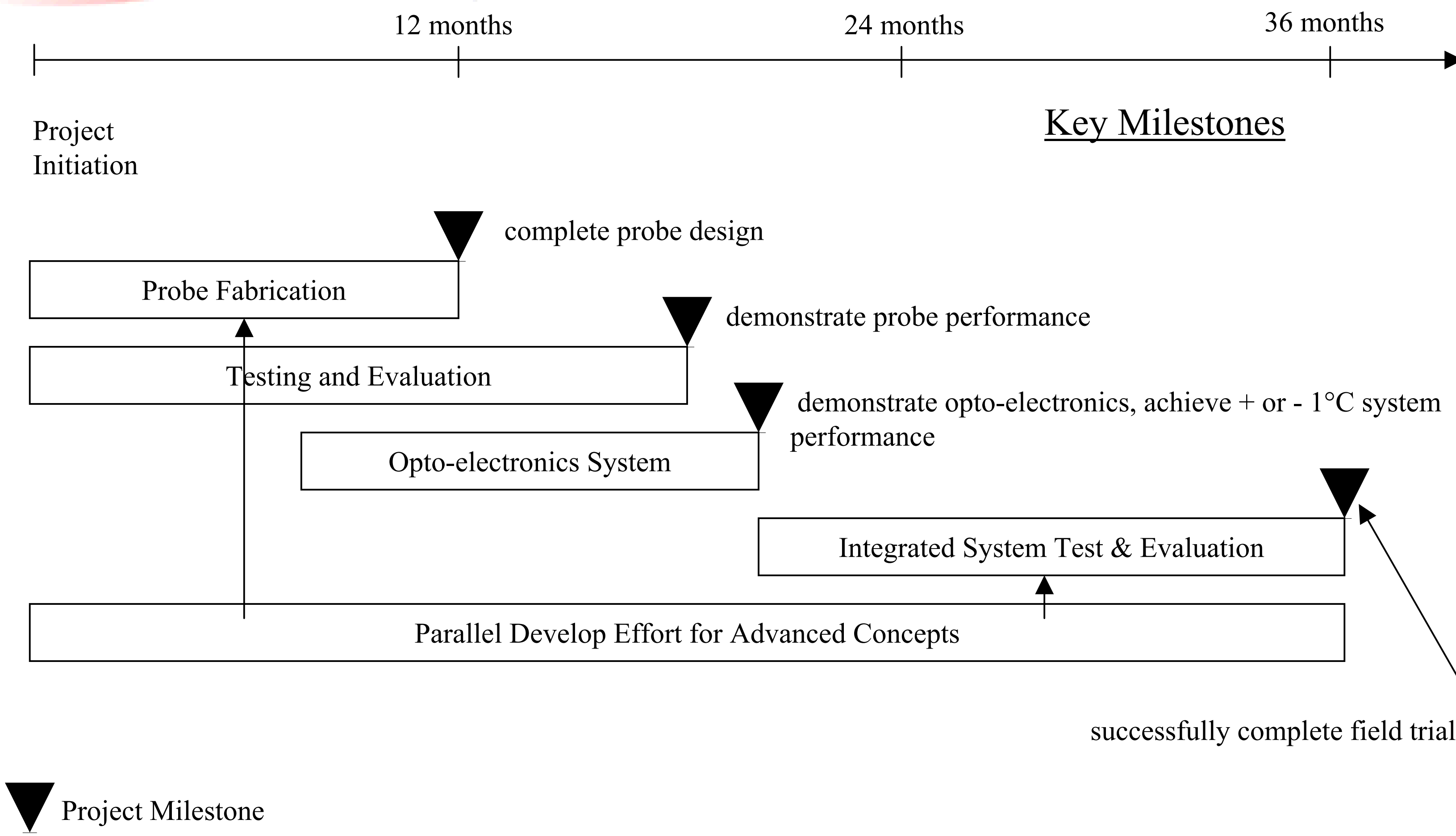
- Identified and tested several effective phosphors and crystals.
- Fibers as small as 50 micron core/110 micron clad have been used in probe trade-off studies.
- Operated demonstrator fuel cell with phosphor deposited on PEM and fiber probe inserted.
  - Verified no degradation to FC operation
  - Attempting to measure very small internal temperature changes caused by operation of cell (200mW power output)
- Identified some novel probe/measurement options that may lead to very precise and low cost sensor options.

Collaboration Efforts

We are Already Working with:

- FreedomCAR Tech Team and Big-3 delegates to gain insight into system-level functional requirements;
- Fuel cell developers to understand implementation strategies and specific operational measurement needs;
- PNNL to fabricate custom fibers for studies;
- NuFern and Translume to develop sensor concepts and advanced concepts that may lead to novel, low cost and versatile probe designs;

Key Milestones



Future Plans

- Continue expanding our collaboration activities to ensure maximum benefit is provided to FC developers and end users - need more input from designers and end users.
- Need access to prototype MEAs or detailed guidance to fully explore the design space - HELP!
- Our plans include a parallel development effort on probe designs
  - Simple terminal sensing to prove concept
  - Advanced designs to push the utility envelope
- We think we can measure other parameters with the same or similar sensor implementation - we need your input.